What is the role of turbulence in molecular cloud formation and evolution

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Five Questions

- What maintains observed turbulence in cores and clouds?
- Does this turbulence support molecular clouds quasistatically, or do they dynamically collapse, then blow themselves apart?
- What determines the cloud mass spectrum?
- Why do molecular clouds form? (triggering vs. gravity)
- How do molecular cloud formation and star formation relate? (correlation vs causation)

Turbulence Drivers

- Accretion
- H II regions
- External SNe
- Jets
- Radiation pressure

3D models of colliding flows

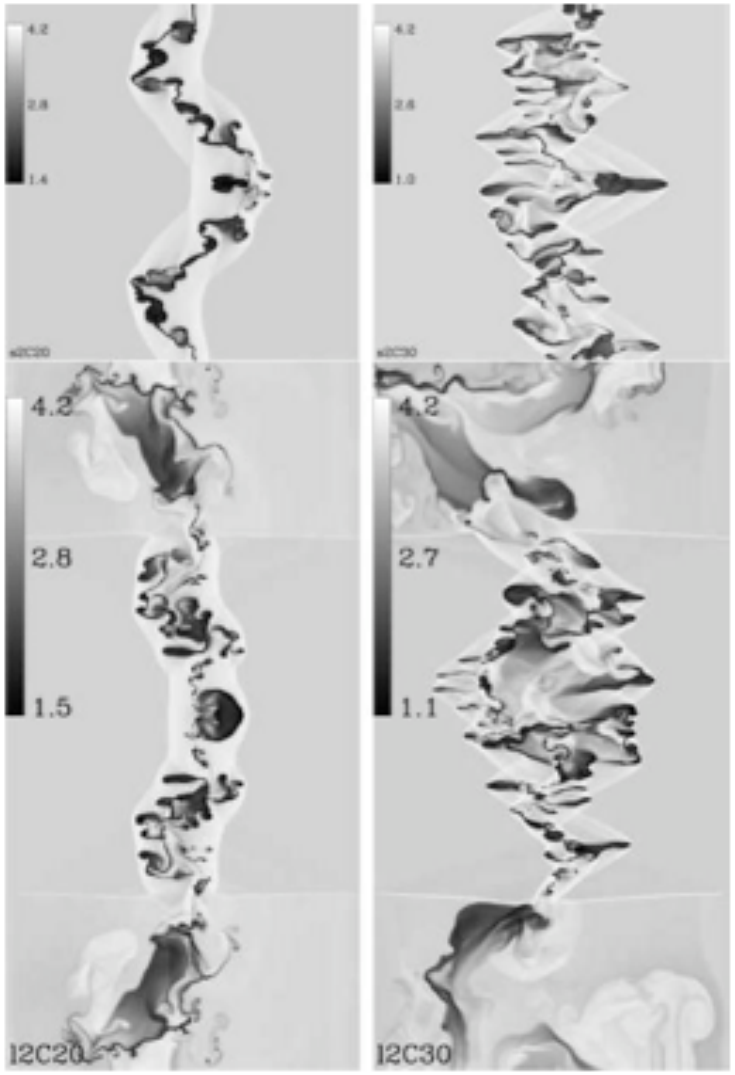
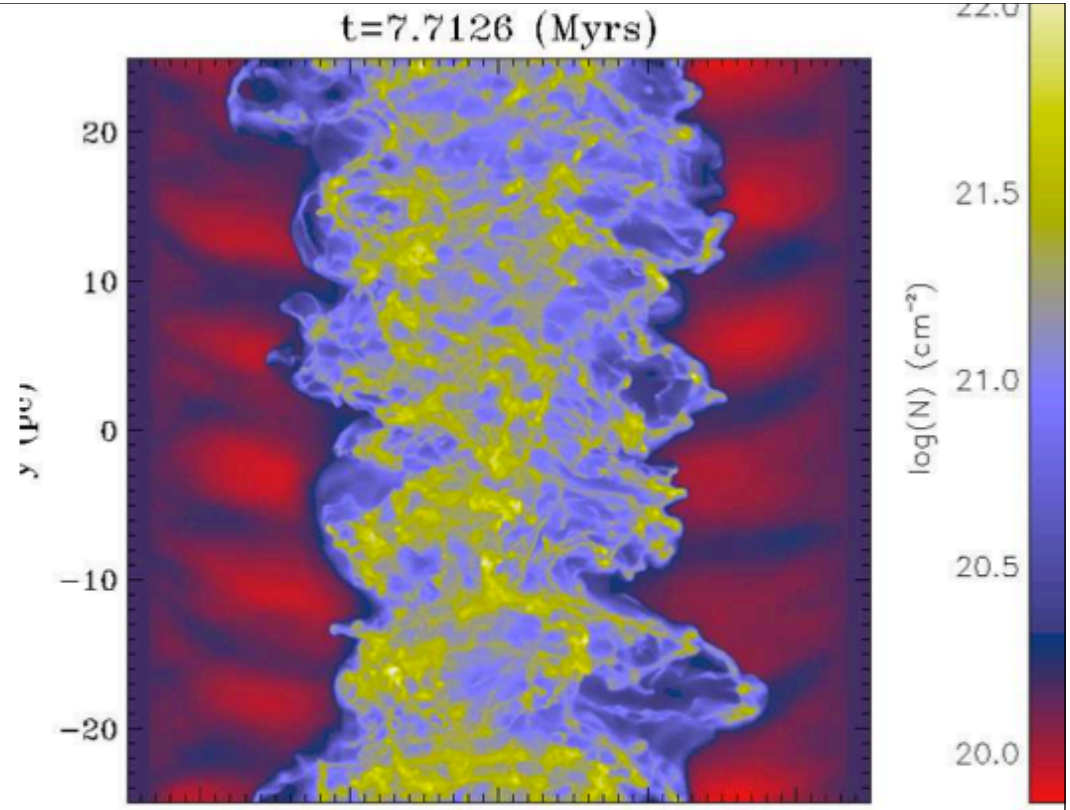
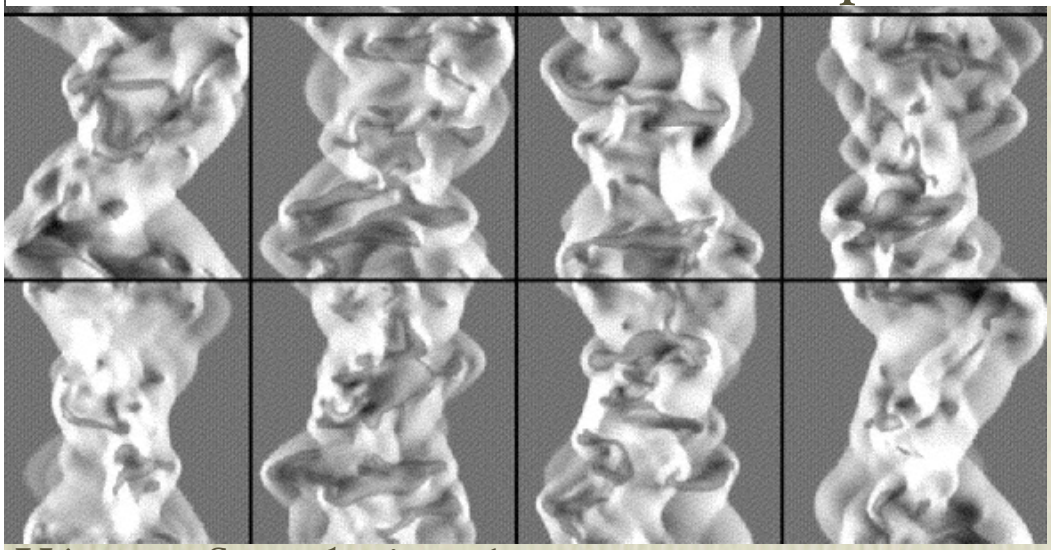


FIG. 19.— *Top:* Stills of models s2C20 and s2C30 with open boundary conditions in the transversal direction. The resolution is $N = 512$. *Bottom:* Stills of models l2C20 and l2C30 with open boundary conditions in the transversal direction and an "inactive" region above and below the inflow. The resolution is $N = 512 \times 1024$.

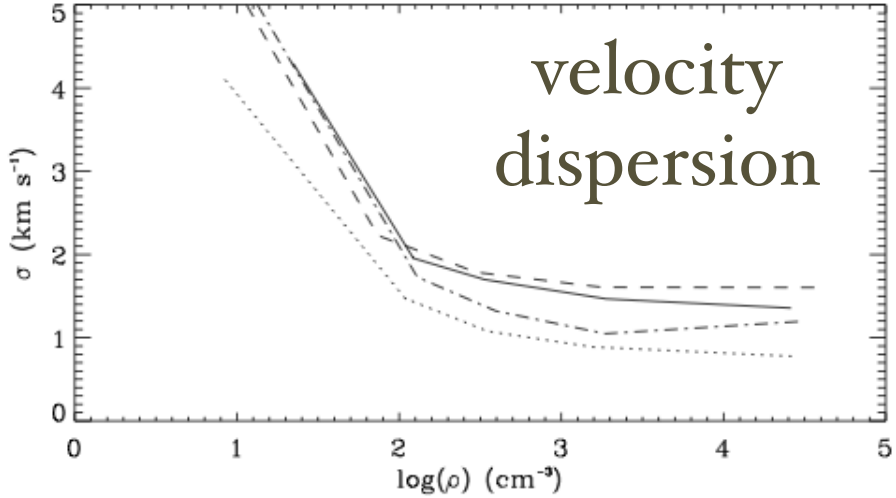
Heitsch +06

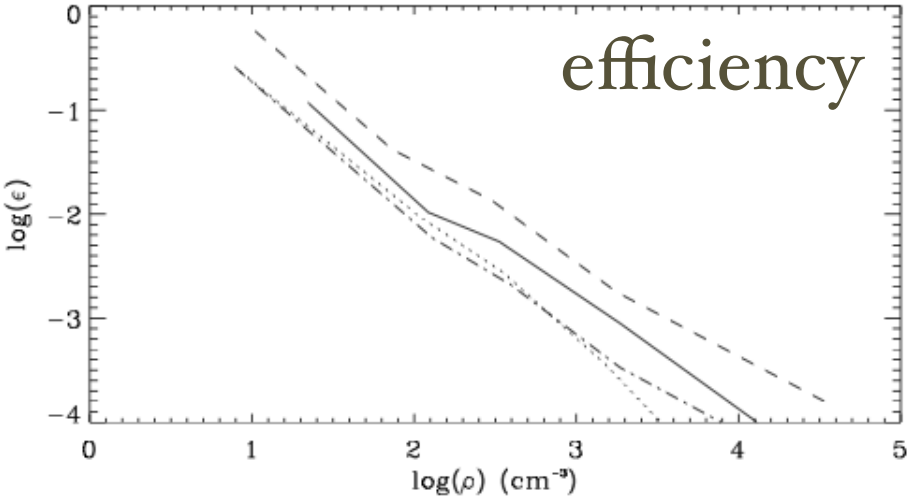


Hennebelle + 08 multiphase

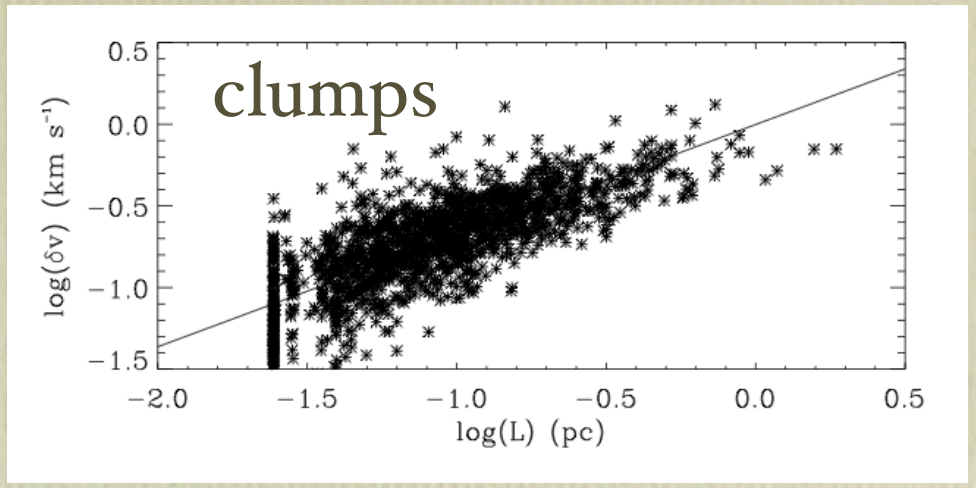


Vázquez-Semadeni + 06 With self-gravity





Klessen & Hennebelle 10 using simulations based on Hennebelle+ 08, Audit & Hennebelle 10



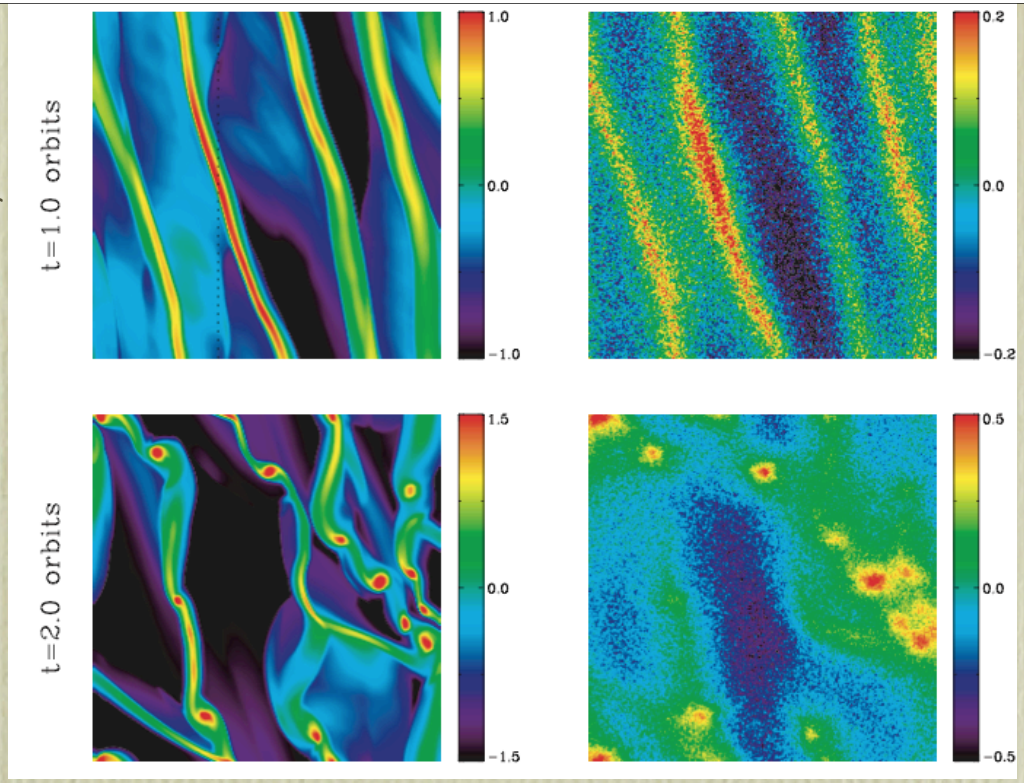
Accretion-driven turbulence

- Fukui + 09 estimates 0.05 $M_{sun}\,yr^{-1}$ for LMC clouds
- converting that with few % efficiency can drive observed turbulence
- converging flow simulations show such efficiency for factor 100 overdensities.

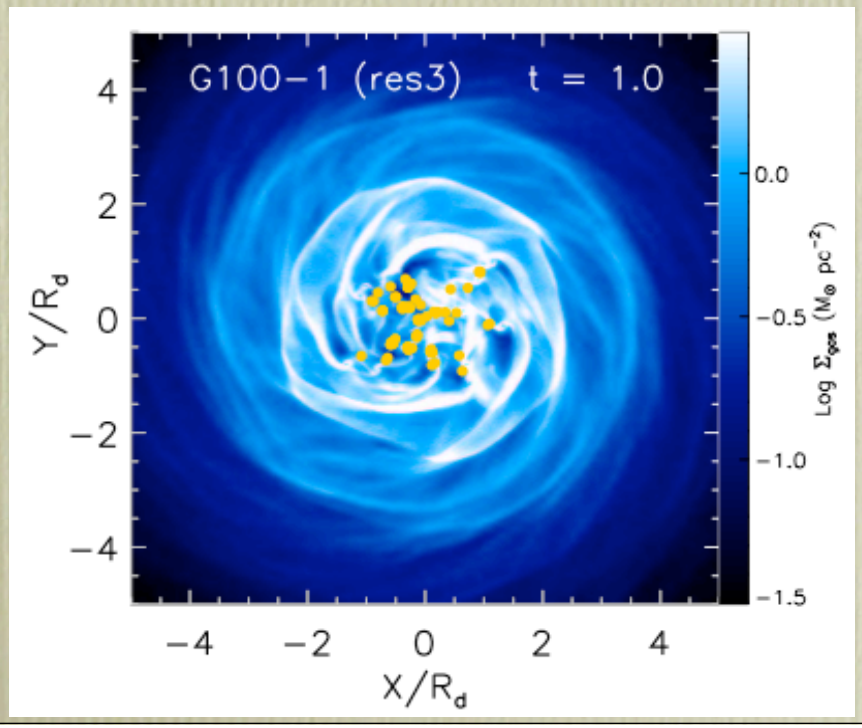
Origin of converging flows?

- Primarily, large-scale gravitational instability
- Secondarily, supernova or MRI-driven turbulence

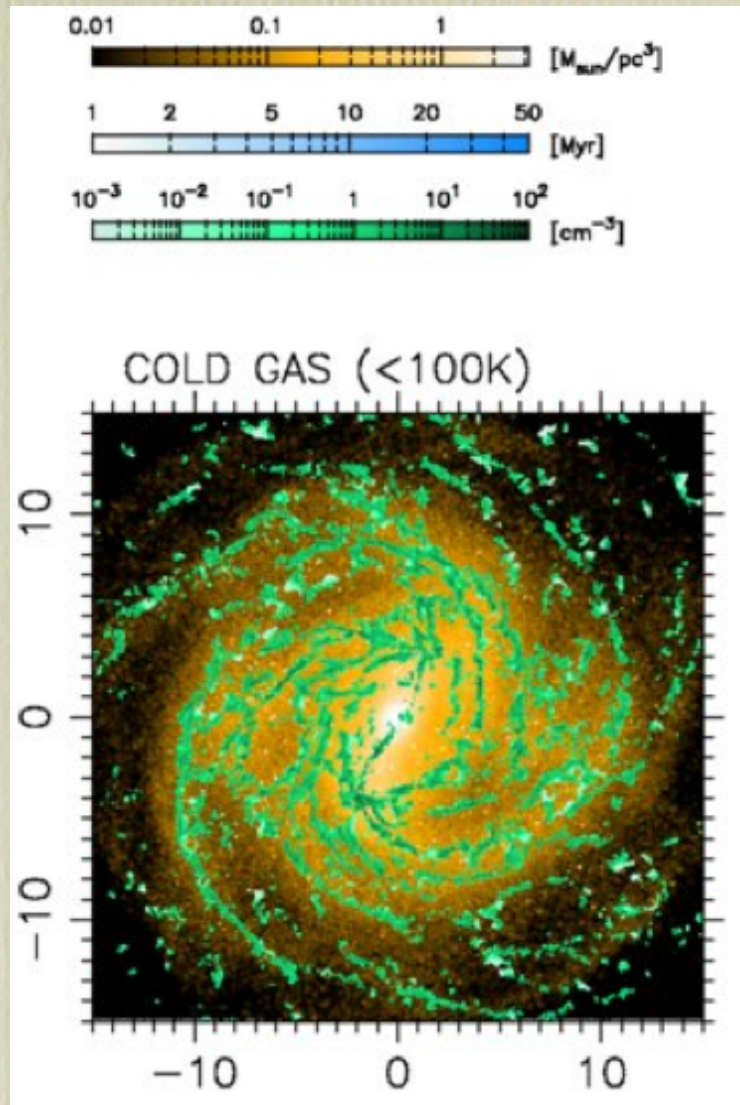
Kim & Ostriker 07



Li, ML & Klessen 05, 06



Baba+ 10

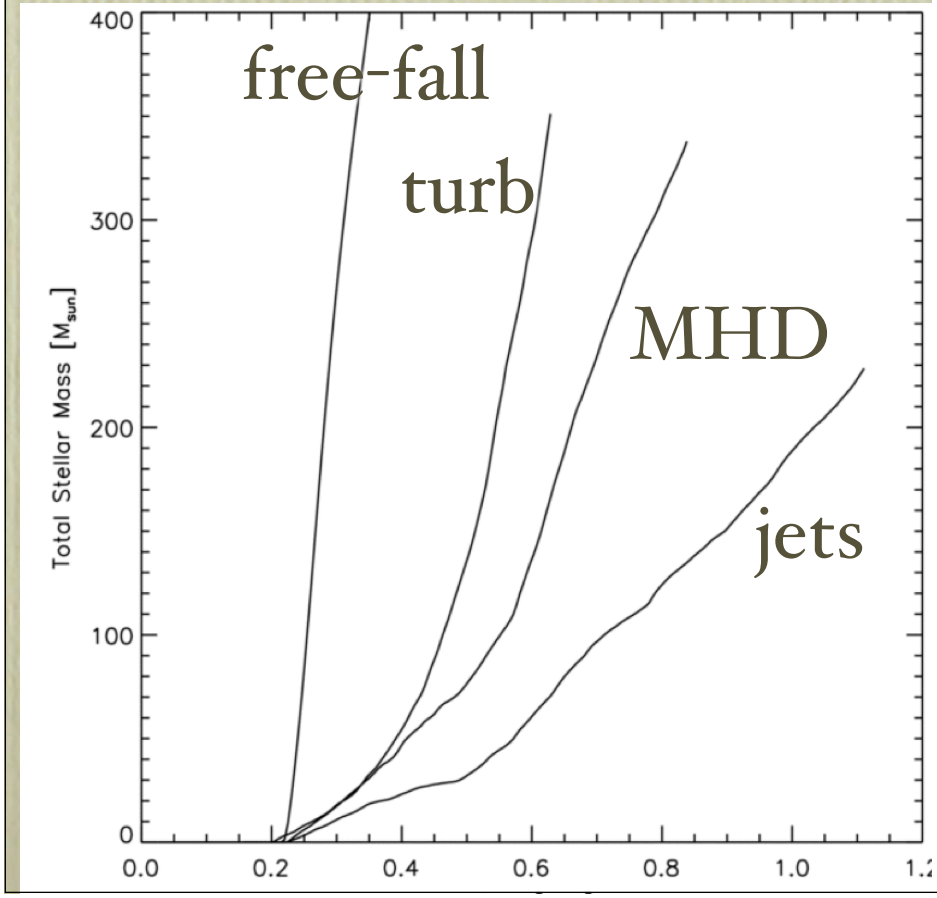


Massive Stars

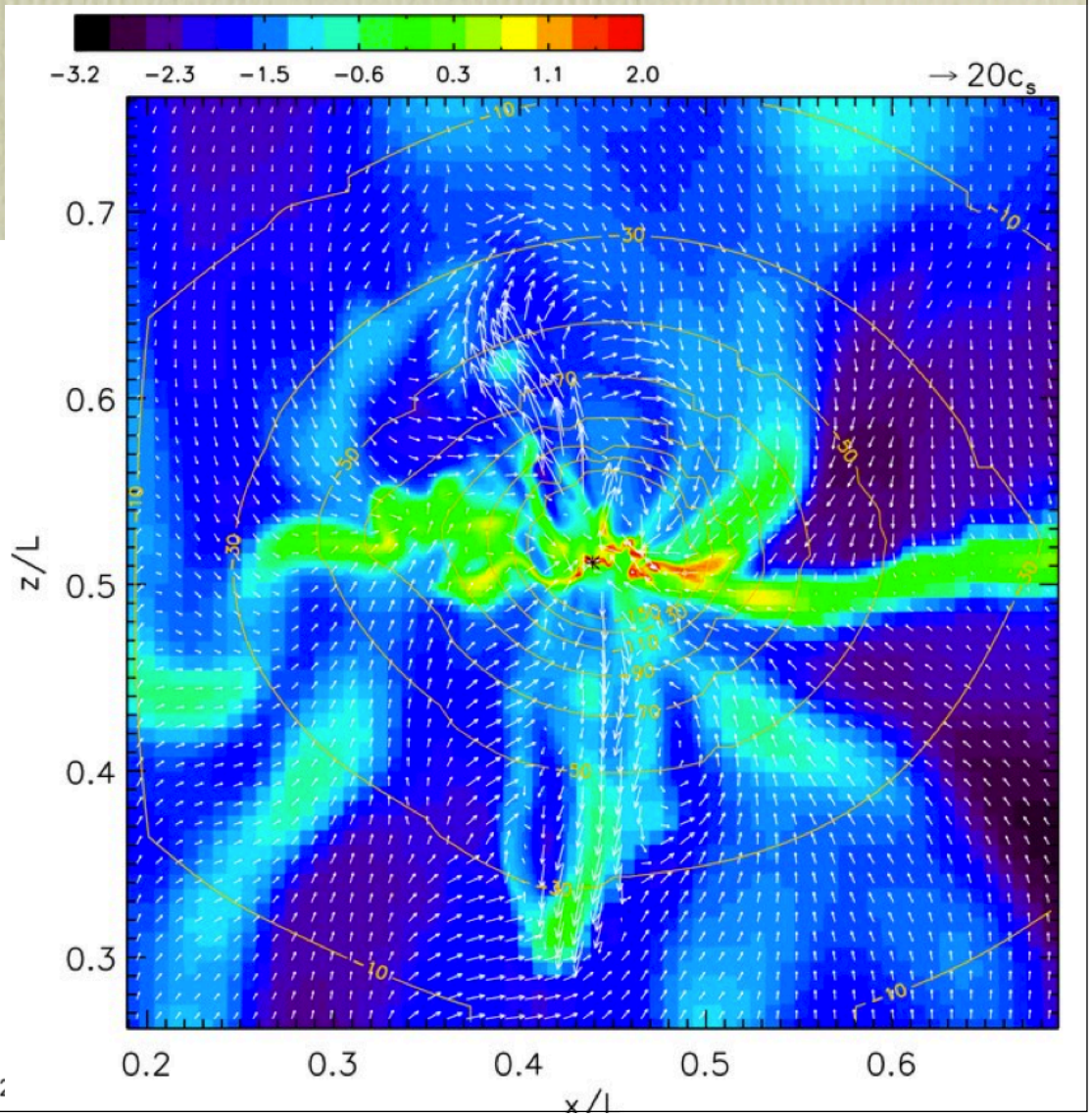
- H II regions: Matzner 02
- Radiation pressure on cloud scale: Fall + 10, Murray + 10
- Supernova & stellar winds (see Banerjee's talk)
  - ineffective at driving material out of potential well
  - stir material up and shape it effectively

Low Mass Stellar Jets

- effective at supporting collapsing clumps
- ineffective at driving turbulence far from site of star formation



Wang + 10



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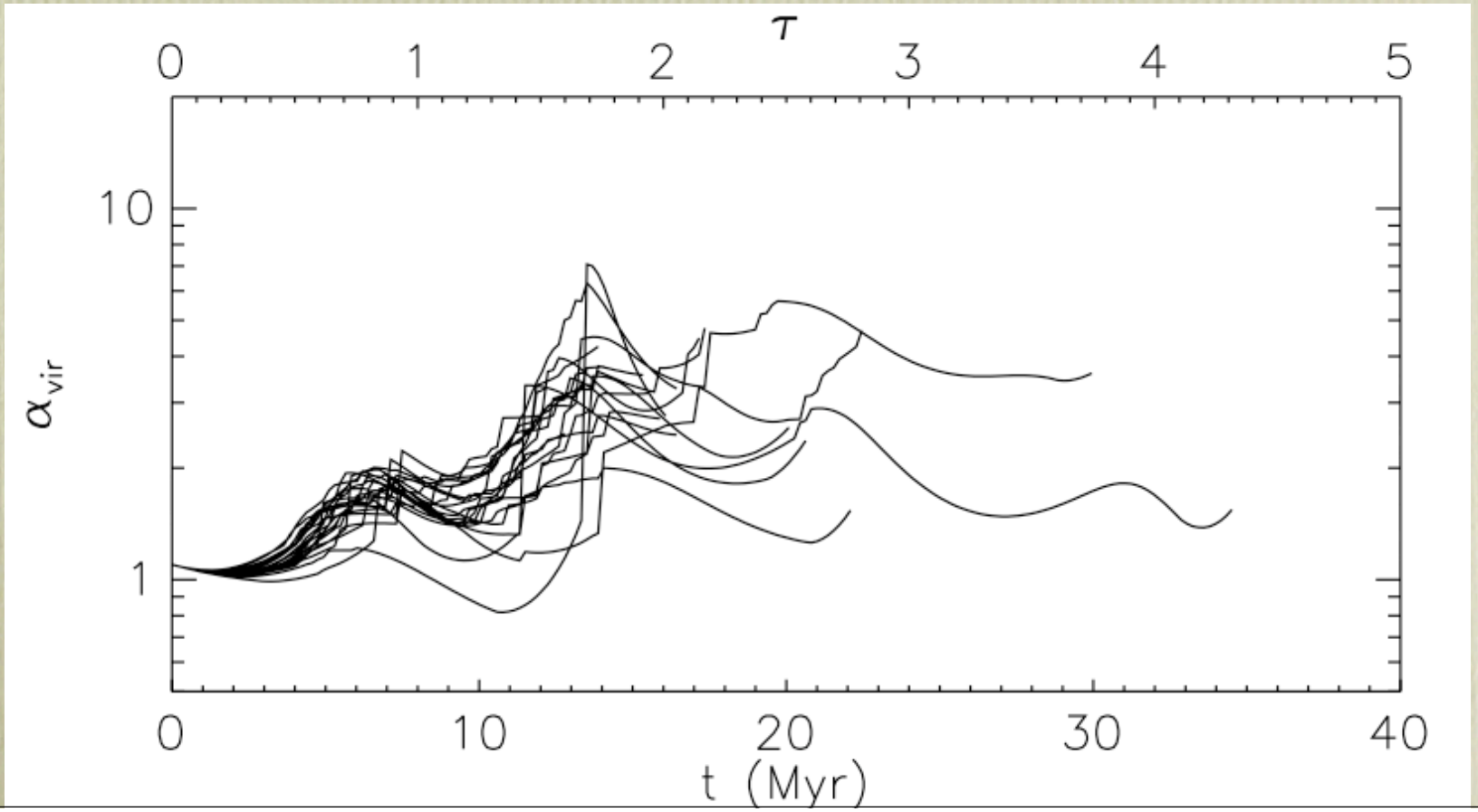
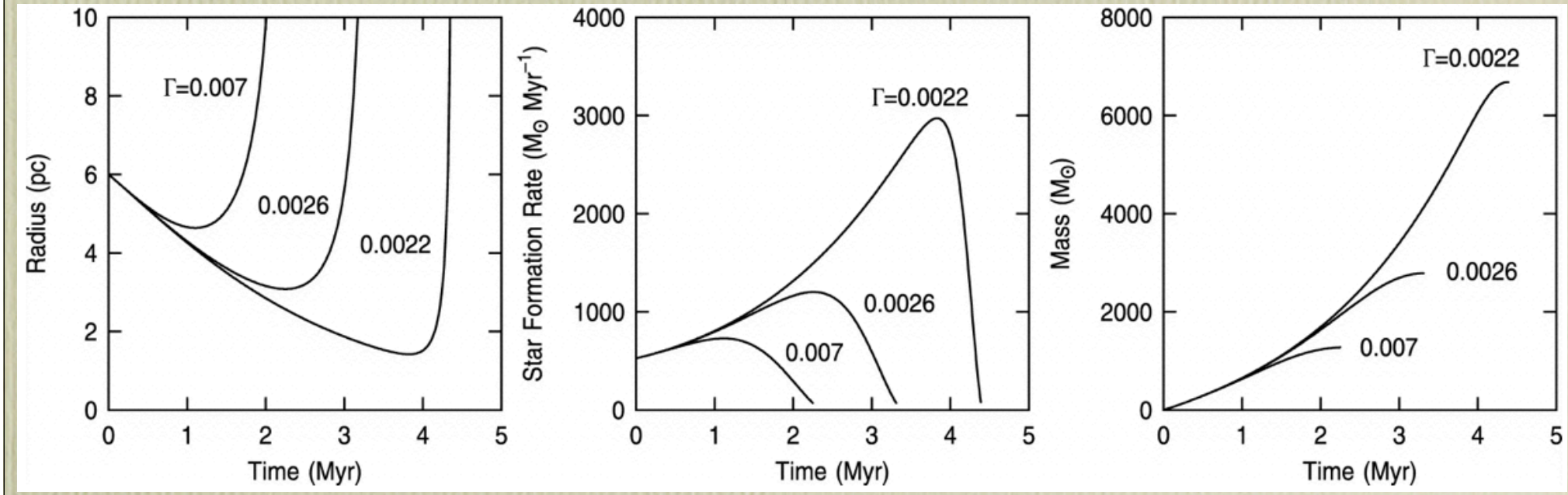
Krumholz, Matzner, McKee 06 use a semi-analytic model to follow GMCs supported and destroyed by HII regions

Assumptions:

- homologous clouds
- power-law profiles
- equilibrium objects
- full energy equation



- Elmegreen 07 found much shorter-lived objects
  - did not assume spherical clouds
  - most deposited energy blown out



Neither model included accretion. Recent semi-analytic work by Vázquez-Semadeni + 10, Goldbaum & Krumholz 10 suggests that accretion results in extended lifetimes, as well as driving turbulence.

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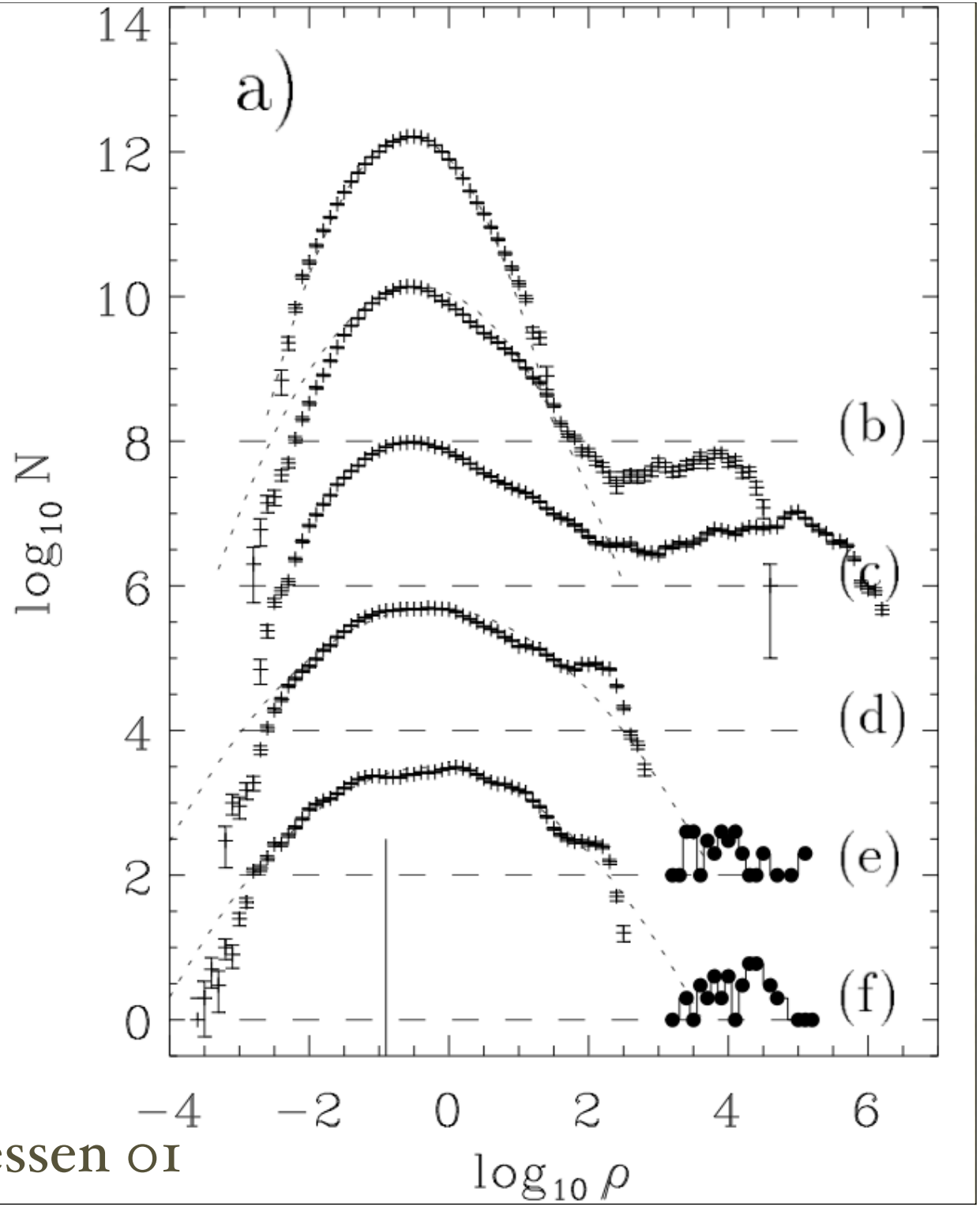
Simulations

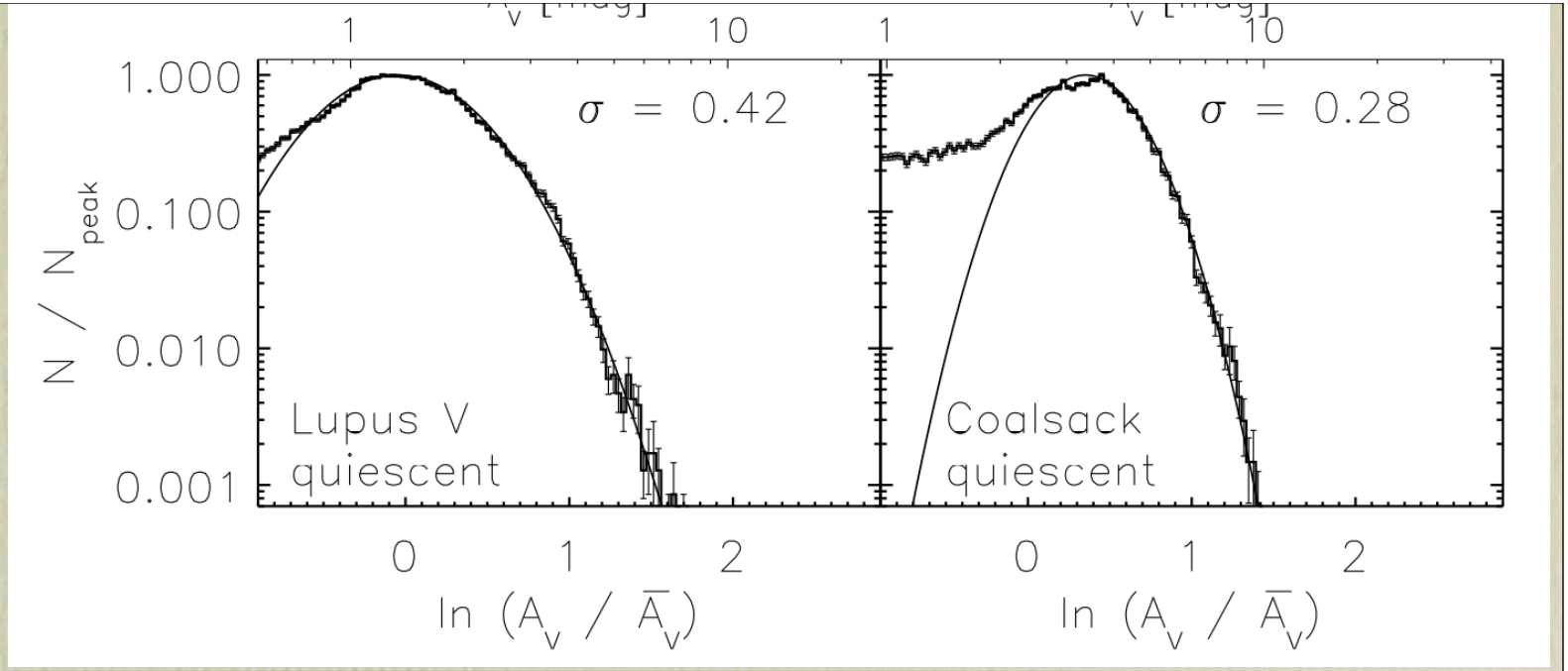
- Turbulent PDF is log normal in absence of gravity.
- High density tail appears when gravity important

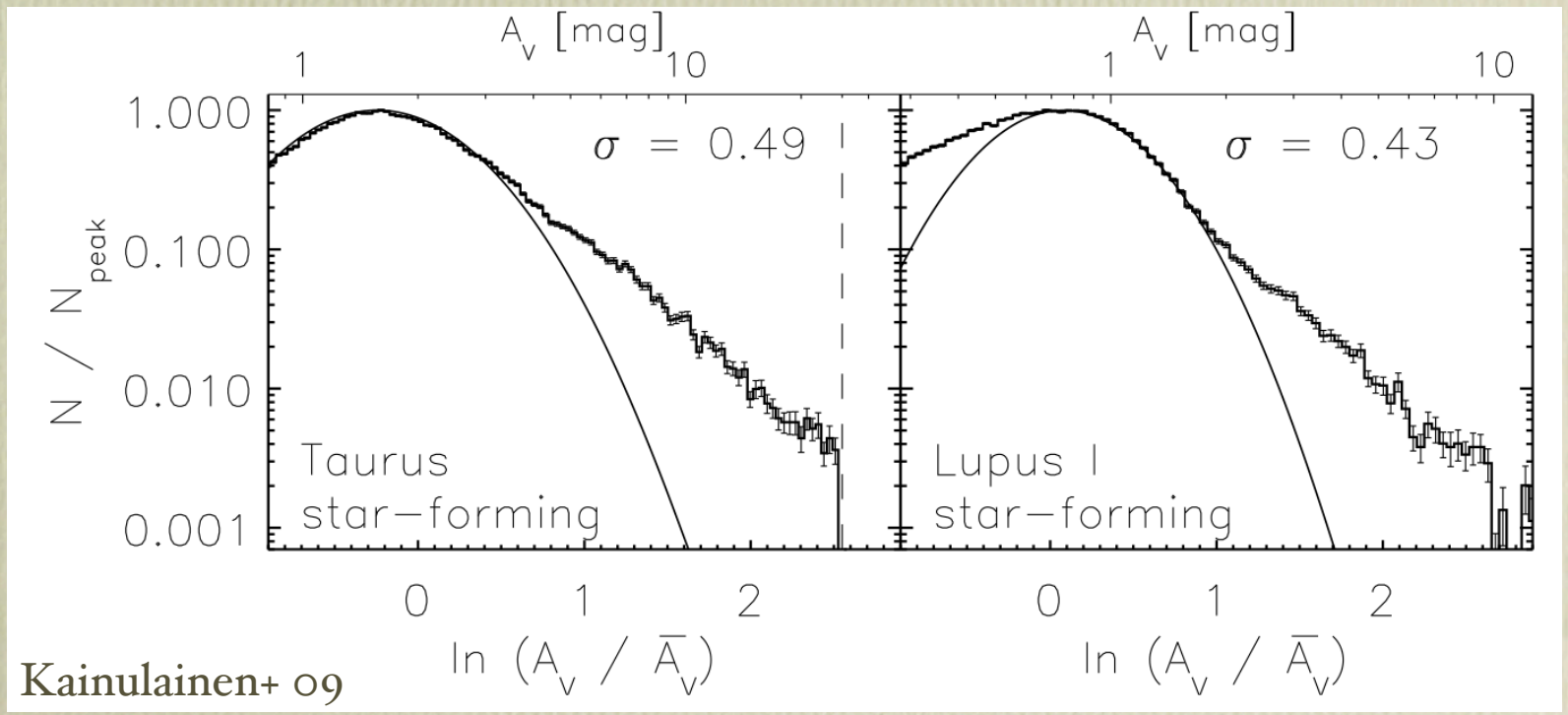


Klessen 01

Observations

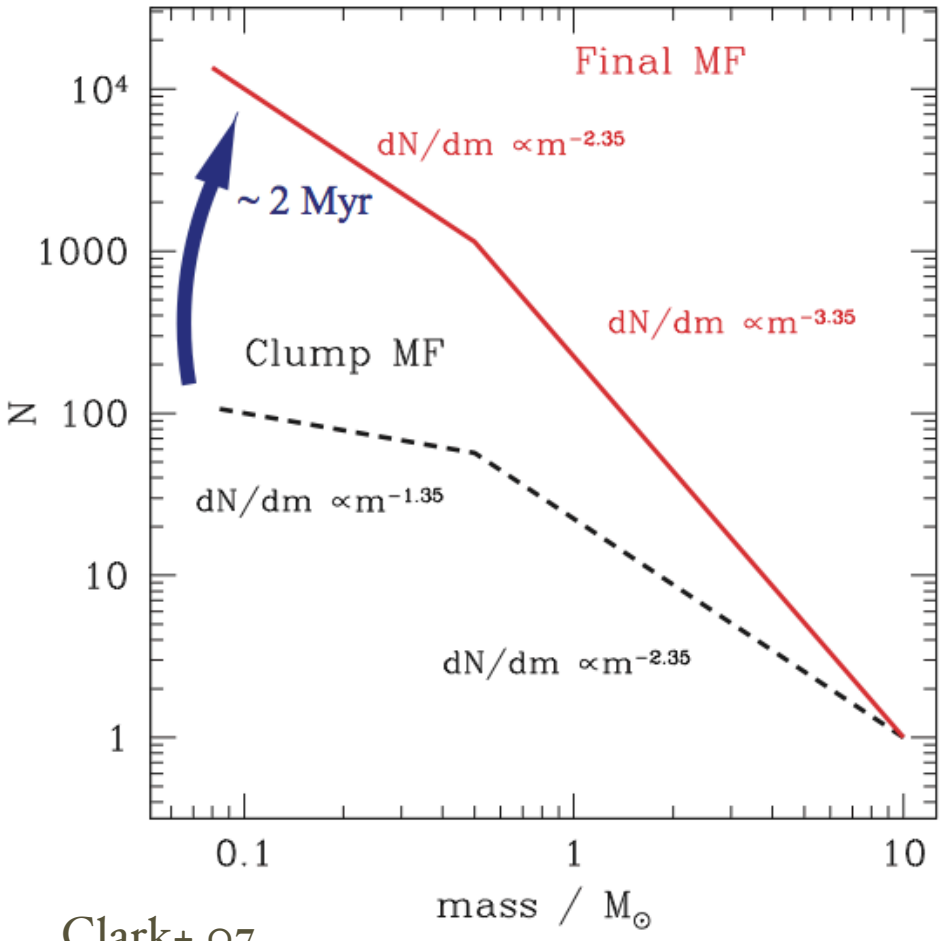
- NICER gives unbiased PDFs
- Quiescent clouds w/o IR sources log-normal
- SF clouds w/IR sources show high density tail.

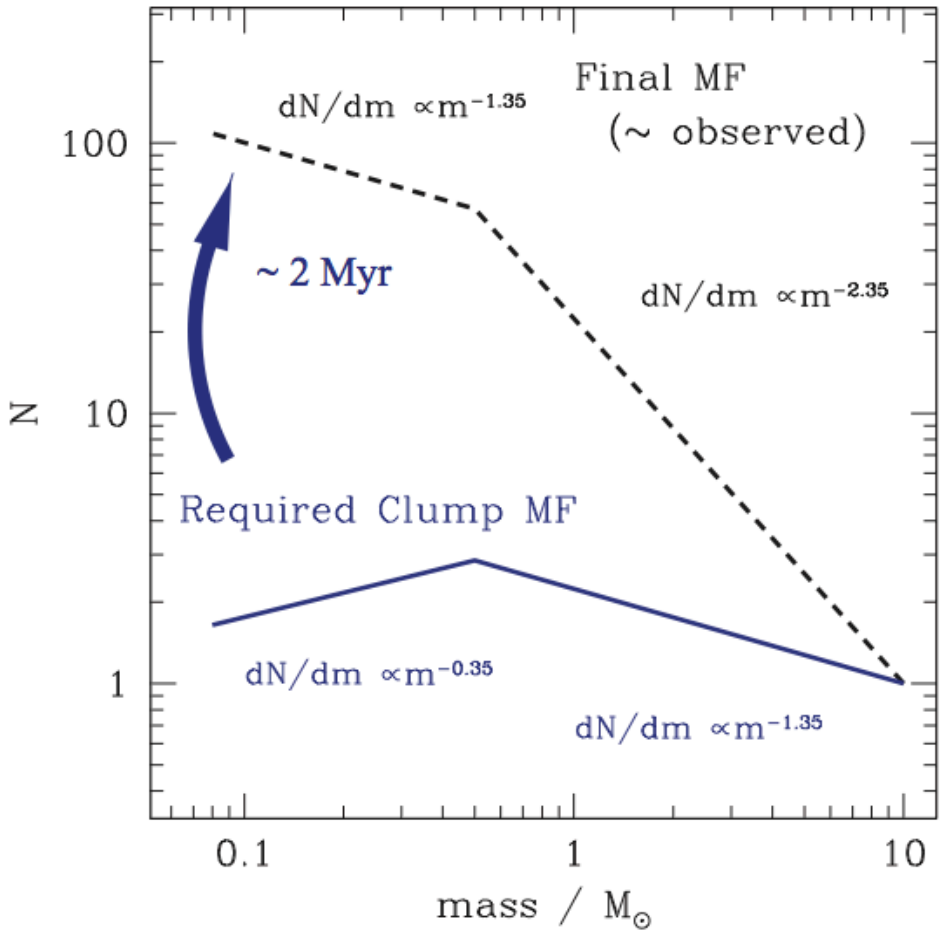




Kainulainen+ 09

If clumps have roughly a Jeans mass each, smaller ones collapse *much* faster than large ones, steepening IMF from CMF





Clark+ 07
(also Elmegreen 93

Note: this work started at EPoS 2006

Fragmentation of single core w/ M >> M_J